Near Surface Gas Mapping Profiles of Salt Geologic Features at the Weeks Island Strategic Petroleum Reserve Site

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ABSTRACT

Field sampling and rapid **g**as **a**nalysis techniques have been developed to survey near-**s**urface **s**oil gasses– including **h**ydrogen, **m**ethane, **e**thylene and **e**thane– for **g**eotechnical diagnostic purposes at the Weeks Island Strategic **P**etroleum Reserve (SPR) site in Louisiana. Several hundred soil gas samples were obtained and analyzed in the field by gas chromatography for profiling low concentrations of the target gasses at ppm to percent levels. Surveys were conducted across two sinkholes, mapped **a**nomalous **z**ones in the **s**alt, and the Weeks Island SPR repository. Additionally, numerous samples were collected for laboratory analysis of target gasses at ppb levels and for stable isotope ratio analysis (SIRA) of the methane in the soil gas. Gasses in the near surface soil can originate from the oil, from within the salt, or from surface microbial activity. Methane SIRA are being used to distinguish biogenic from petrogenic methane.

Elevated levels of hydrogen and methane are associated with anomalous zones in the salt dome and with suspected salt fracture (dilatant) zones, particularly over the edges of the SPR repository. Significantly elevated areas of hydrogen, methane, and ethane were found in the vicinity of anomalous zones in the salt. We propose that the near-surface gas mapping results are useful for locating anomalous, gassy zones and other structural features at SPR sites and possibly at other salt domes. Gas analysis techniques, current data and interpretations, application of soil gas surveying to monitor and detect subsurface geologic features and fingerprinting sources of hydrocarbons are discussed.

INTRODUCTION

The use of near surface geochemical surveys has experienced a revival recently for oil exploration and geological investigations. The advent of accurate, portable, and reliable analytical instrumentation has provided field geologists and mineral prospectors with the means to effectively obtain *in situ* chemical analyses in a field setting. The availability of on-site analysis allows one to perform a geochemical survey over wide areas with sufficient spatial resolution and replication to address the inherent heterogeneity of surface soil environments. Near surface soil gas measurements have been used successfully for locating oil reservoirs[1] , fault zones[2] and have been correlated with seismic events.[3] This technique is appreciably less expensive, quicker and simpler than traditional geophysical techniques, yielding a distinct advantage in appropriate situations.

The purpose of this study has been to use near surface gas survey techniques at the Weeks Island Strategic Petroleum Reserve (SPR) site to diagnostically profile low concentrations of selected components (hydrogen, methane, other hydrocarbons) across two sinkholes, mapped anomalous zones in the salt dome and the SPR petroleum repository. These gasses can originate in the repository oil, in the rock salt or, possibly from surface microbial activity. Near surface soil gas surveys are assumed to provide good indicators of gas transport through suspected salt fracture (dilatant) zones over the edges of the SPR repository. Further, high concentrations of hydrogen and methane, predominantly, can be useful indicators of other features in salt domes, and may be applicable to other SPR sites, salt mines or cavern storage sites. Among the features problematic to salt dome utilization are anomalous zones and otherwise gassy zones (i.e., underground pressurized gas pockets) in the salt.

We used the near surface gas survey techniques over known or suspected geologic features at Weeks Island to evaluate potential relationships between near surface soil gas composition and geologic salt features. Preliminary data and interpretations tend to support the relationships between near surface soil gas composition and geologic structures in the salt.

EXPERIMENTAL

WEEKS ISLAND GEOLOGY

Weeks Island, one of the Five Islands salt dome chain on the south central Louisiana coast, comprises uplifted late Wisconsinian Peoria Loess covering alluvial deposits of the Prairie Complex. The geology of Weeks Island has been described in detail previously[4] and will only be summarized here. Topographic features of Weeks island were formed by diapiric uplift, sediment reworking, drainage network development, and localized subsidence. The "Devil's Backbone", a generally north-south ridge underlain by loess covered sandy deposits, occupies the highest part of the island at elevations up to 52 meters. Shear Zone D (see Figure 1) has been mapped in association with this ridge[5,6]. A sinkhole that developed in approximately 1992, is near the projected alignment of Shear Zone E[5].

Surficial sediment at Weeks Island represents sediment of the late Pleistocene Prairie Complex and sediment veneers that cover the Prairie Complex.[7,8] In and around the Five Islands, surficial sediments of the Prairie Complex consist of ancestral Mississippi River fluvial deposits. Surface veneers include Peoria Loess, a basal loess mixing zone, overwash colluvium, gully fill sediment, and Holocene marsh deposits. Peoria Loess is a brownish silt loam with a friable consistency, becoming slightly plastic or sticky when wet. Perched water occurs at or near the base of the unit where loess is underlain by clayey sediment. The surface soil covering most of Weeks Island is a Memphis Silt Loam (Typic Hapludalf) with moderate blocky structure and clay films on peds. The maximum loess thickness cored by Autin et al.[6] was 380 cm. The Peoria Loess mixing zone has a modal thickness of approximately 50 cm and is normally a brown to yellow silt loam to sandy loam with weak blocky structure and friable to sticky consistency. Overwash colluvium can reach approximately 150 cm thickness and is a gray to brown silt loam. Gully fills are gray brown silt loam to loamy sand. Holocene marsh sediment at Weeks Island is a very dark gray to black silty clay loam to mucky clay with fibric to hemic reed, grass and wood fragments.

Several Shear zones have been tentatively mapped in the salt stock at Weeks Island.[9] These areas are interpreted to represent the interface of individual salt spines moving differentially during the upward migration of the salt stock.[10] Internally, these areas are characterized by intense folding and banding of the salt and the inclusion of foreign sedimentary material as well as brine, oil and gas. This naturally reduces the physical homogeneity of the salt stock and could be expected to provide multiple higher permeability pathways for the escape of entrained gas. In room and pillar mines, such as those at Weeks Islands, Shear zones are associated with "blowouts" where pockets of salt break out during routine blasting. Figure 1 shows the location of the various Shear zones, labeled A-E, identified or suspected at Weeks Island.[5]

Mining operations have been ongoing at Weeks Island for many years. The two mine levels at approximately -535 feet and -735 feet were filled, beginning in 1980, with crude oil as part of the Strategic Petroleum Reserve Program. In 1992 a sinkhole was discovered near Shear Zone E above the southern boundary of the upper (500 foot) mine level. In 1995 a second, smaller, sinkhole was discovered above the northwestern perimeter of the upper mine level.

SOIL GAS SAMPLING PROCEDURE

Since April 1995, four areas at Weeks Island have been surveyed using near surface soil gas concentrations of hydrogen, methane, ethylene, ethane, propylene and propane. Approximately 270 samples were analyzed on site for hydrogen and methane on 10 days over the period between April and July 1995. Additionally, almost 130 samples were collected for laboratory analysis of C1 to C5 hydrocarbons. Though 270 may seem like a large number of samples, the density of samples in the survey is actually rather low. The survey covered a fairly large area, with at least four major differences in important factors that can affect soil gas concentrations: location with respect to anomalous zones, location with respect to mine perimeters, surficial soil type, and natural temporal variations in absolute gas concentrations. Thus the data are spread thin and, while significant trends can be identified and strong hypotheses made about the origin of the soil gas anomalies, drawing specific, definitive conclusions about gas sources and subsurface geology and engineered structures may be premature.

Two of the surveyed areas were transects near Shear Zones A and D (WK and WL, Figure 1). A third transect was oriented above the eastern perimeter of the upper mine (WM). Sample points on transects were generally 10 meters apart. Finally, an area near the location of the second sinkhole (W2) was briefly surveyed. A fifth location (northeast of Figure 1) was occasionally sampled as a background region removed from the SPR facility and salt mining activities. This background location was topographically similar to the area above Shear Zone A but was located near the northeastern edge of the dome near the intersection of Snyder Rd and LA Hwy 83.

The first sampling transect (WK) was outside the perimeter of the upper mine for its entire 700 meter length. Transect WK crossed the lower (700 foot) mine boundary at approximately 400 meters from the transect origin (0 meters) on the crown of the Devil's Backbone ridge. Oriented normally to Shear Zone A, transect WK crossed over the mapped boundary of the Shear zone near the intersection of Shear Zones A and D. The mapped boundaries of the shear zones represent their estimated locations in the salt and, while the surface expressions should lie somewhat above the feature, the mapped boundaries may not exactly coincide with the surface location of associated anomalies.

Transect WL was located above the eastern perimeter of the lower mine within the mapped boundary of Shear Zone D. The salt at the lower mine level beneath this transect was known to contain pressurized gas pockets and to be subject to blowouts. The transect ran generally north-south, parallel to Snyder Road, for 280 meters.

The third transect, WM, followed the upper mine perimeter from Snyder Road northward for a distance of 380 meters. The location was fairly well removed from any known accumulations of gassy salt or previously mapped shear zones. Transect WM crossed a set of three deep ravines, running east to west. At several points along this transect additional samples were taken at points inboard and outboard of the mine perimeter, but on the same landscape position with respect to the ravines, to explore the effect of the mine perimeter (e.g., dilatancy) on the soil gas readings.

The final location surveyed on Weeks Island during this period, area W2, was above the northwest perimeter of the upper mine near the location of the second sinkhole (see Figures 1 and 7). A short transect ran from monument UL62 northward for 50 meters. Additional sample locations were distributed around an area encompassing monuments UL62 through UL56. These locations included points inboard and outboard of the upper mine perimeter. Samples were also taken from the sand fill in the sinkhole, which was about 5 m in diameter by 3 m deep, and from the native soil at the edges of the sinkhole.

GAS ANALYSIS PROCEDURE

Soil gas samples were taken from a depth of slightly over 150 cm (5 feet) using a sampling device as depicted in Figure 2 attached to a 0.63 cm (1/4 inch) stainless steel sampling tube . At each sample location a 90 cm (3 feet), 1.3 cm (1/2 inch) diameter pilot hole was drilled with a power drill or similar device. The sampling tube, fitted with a removable drive tip, was then inserted into the pilot hole and pressed to a total depth of 170 cm (5.5 feet). After withdrawing the probe 5 cm (2 inches) to dislodge the drive tip, the gas sample was drawn into the evacuated sample holding cylinder. A 5 ml portion of the gas was removed from the holding cylinder and analyzed immediately with a portable gas chromatograph (GC).[11] The on-site analysis targeted helium, hydrogen and methane. In many samples however, helium and methane concentrations were below the detection limits of the portable GC. For a number of samples, an additional 50 ml portion of gas was collected in sample bottles for hydrocarbon analysis with a more sensitive laboratory GC. The laboratory GC allowed the samples to be analyzed for methane, ethylene, ethane, propylene, propane and other C4-C6 hydrocarbons at low ppb levels. Except for small amounts of butane, no C4 or higher hydrocarbons were detected in the soil gas at Weeks Island. Approximately 10 samples were similarly collected for methane stable isotope ratio analysis (SIRA). Stable isotope ratios for hydrogen and carbon in methane can help to distinguish between petrogenic and biogenic methane sources although perhaps not between modern and ancient biogenic methane.[12]

RESULTS

The soil gas survey provided two types of information about the soil gas, concentrations of the target analytes as a function of location and the relative concentration of analytes at a given location. The bulk of the data, obtained with the portable GC, pertained to the trends in hydrogen and methane concentrations across the landscape of the island. The extended hydrocarbon analyses of the samples returned to the laboratory provided the lower detection limits necessary to determine soil gas concentrations of not only methane, but also ethane, ethylene, propane and propylene.

HYDROCARBON PROFILES

Three distinct hydrocarbon patterns were found at Weeks Island. Figure 3 shows typical chromatographic traces for two of the hydrocarbon profiles. The calibration standard contains the C1-C4 alkanes (methane through butane) and the corresponding 1-alkenes (e.g., ethylene, propylene, etc.) at 1 ppm each. The standard components elute in pairs with the 1-alkene immediately preceding the corresponding alkane. The chromatogram of the soil gas from the background area typifies the hydrocarbon profile found at most locations surveyed on Weeks Island. Ethane and ethylene were present in approximately equal amounts as were propane and propylene. The same appears to be true for butane as well, though concentrations near method detection limits made such a determination difficult. The hydrocarbon profile of soil gas samples taken from the 250 meter point on transect WK, on the other hand, showed a pronounced absence of alkenes, even when ethane concentrations approached 5ppm. The preponderance of alkanes over alkenes in the hydrocarbon profile argues against a near-surface biogenic source for these hydrocarbons.[13] The third type of profile (not shown), thought to suggest near surface biogenic origin, contained high methane concentrations, above 2000 ppm, but no detectable higher hydrocarbons (C2 and above) above 50 ppb. SIRA of the soil gas hydrocarbons currently underway should help to clarify whether the source of these hydrocarbons is petrogenic or biogenic although as mentioned above, it will not differentiate between ancient and modern biogenic sources.

HYDROGEN AND METHANE TRENDS

Hydrogen concentrations in the soil gas closely paralleled methane concentrations through the entire survey. Transect WK hydrogen and methane trends, shown in Figure 4 exemplify the correlation between hydrogen and methane results. The methane detection limit of the portable gas chromatograph was high enough (>10 ppm) that the methane in many samples was undetected. Thus, the more complete set of methane data came from the extended hydrocarbon analysis performed in the LSU Institute for Environmental Studies laboratories and to avoid confusion, only the laboratory results for methane are presented here. The relatively small number of samples returned to the laboratory, however, limited the spatial resolution in the methane data. Consequently, some uncertainty remains about the specific sources of the observed trends.

The most significant feature in the soil gas trend on transect WK is the very large spike in hydrogen and methane concentrations at approximately 250 meters (sample location WK250). This feature was observed on successive trips in May, June and July. The peak methane level for the data shown in Figure 4b was approximately 2000 ppm, though methane levels at this location were sometimes as high as 2%. The high methane concentration at WK250 was consistently the highest value along the transect. The 250 meter point was unique as mentioned earlier in having no detectable ethylene and propylene in the soil gas. On different surveys of the transect, the precise location of the maximum has varied by ±10 meters (10 meters was the spatial resolution used in this survey). Occasionally, the loci of the hydrogen and methane concentration maxima have differed by 10 meters. A second feature on transect WK was a small but noticeable drop in hydrogen levels (corresponding methane levels were not available) as the transect crossed the 400 meter mark, approximately where the transect crossed above the mine perimeter. In May, hydrogen readings at the 400 meter point were 10 times the average readings at 650 meters. The northern extreme of transect WK (positions beyond 550 m, including positions above the mapped location of Shear Zone A) consistently yielded the lowest readings along the transect for both hydrogen and methane. The southern extreme of WK (0 to 100 meters) sometimes had elevated hydrogen levels along with slightly elevated methane levels. While the hydrogen levels on one occasion were nearly as high as at WK250, methane concentrations, though somewhat elevated, did not approach similarly high levels. Further, the soil gas in the 0-100m segment of transect WK contained approximately equal concentrations of ethane and ethylene and approximately equal concentrations of propane and propylene, suggesting at least some biological or chemical action[13].

Transect WL was slightly analogous to a northern segment of transect WK. Located above the mapped location of Shear Zone D and over the perimeter of the lower SPR mine, transect WL corresponds to points at approximately 400 meters on transect WK. The comparability of the two locations is limited by the location of transect WL in a transitional area where the soil is changing from brown to gray due to a wetter soil moisture regime.[6] Like the sampling points just south of

WK400, methane concentrations on transect WL were consistently higher than those at the northern extreme of transect WK (points beyond 500 m). Though methane concentrations vary along transect WL, as shown in Figure 5a, even the lowest methane concentration measured along transect WL was more than three times higher than the corresponding value at the northern extreme of transect WK. More representative of the transect as a whole, however, were the samples at the 180 meter point on transect WL which were almost an order of magnitude higher than those at the northern end of transect WK. A high methane reading at the 140 meter point was near a drainage ditch crossing Snyder Rd and so is the most likely of any sample from the survey to contain large amounts of near-surface biogenic methane. This point had a methane concentration near that measured at WK 250, approximately 1%. SIRA tests are currently underway to confirm the biogenic origin of this gas. Importantly, methane was the only hydrocarbon detected in the soil gas at WL 140 while during the same time frame the soil gas at WK 250 also contained ethane at roughly 5 ppm. Again, significant ethane concentrations at WK 250 were not accompanied by detectable ethylene concentrations. This marks an important difference between the biogenic methane at WL 140 and petrogenic soil hydrocarbons at WK250. Hydrogen concentrations along the WL transect, shown in Figure 5b, weakly paralleled methane concentrations, but were not as elevated with respect to the northern extreme of transect WK as methane; the median hydrogen concentration from transect WL was 2 to 3 times higher than the corresponding value from the northern end of transect WK.

Transect WM ran north-south above the eastern perimeter of the upper SPR mine and was considerably further from Shear Zone D than was transect WK. Transect WM crossed a portion of the Devil's Backbone ridge that is in the process of being dissected by gully erosion. The gullies trend east-west and cut almost normally across the transect. Absolute concentrations of all gases were low during the time period that this transect was surveyed. The soil had been relatively dry for several weeks prior and the porosity of the predominantly sandy surface soil is high; this led to greater atmospheric exchange and consequently low soil gas concentrations. During this period the absolute concentrations of target analytes were also significantly lower at other, previously surveyed locations. Because of the generally low concentrations during this period, many of the samples contained concentrations of the target analytes below detection limits. Thus the hydrocarbon profile, other than methane concentration, was unavailable for any of the locations on transect WM. The number of locations for which hydrocarbon samples were taken during this time was small, 4 for transect WL and 6 for transect WM. In Figure 6a, the data from the transect have been separated with respect to the sample location relative to the mine perimeter. Sample points were classified as IN or OUT if they were clearly inboard or outboard of the mine perimeter; otherwise they were classified as being above the mine perimeter and labeled as EDGE. Inboard and outboard samples taken at the same distance along the transect came from the same landscape position. The data are again unfortunately sparse; but where inboard and outboard results can be compared, the outboard methane concentrations were consistently higher. The corresponding hydrogen concentrations show a similar tendency toward higher values for outboard measurements (Figure 6b). Additionally, the hydrogen concentrations oscillate with position along the transect, roughly reflecting the topography of the transect, but with clearly higher concentrations in the first 50 meters. The hydrogen data may reflect methane trends as they do at the other Weeks Island locations, but the methane results are simply too few to be certain.

The final surveyed area at Weeks Island, area W2, was on the northwest perimeter of the upper mine boundary near the site of a sinkhole (Sinkhole #2) discovered in early 1995 (Figure 7). Samples were distributed widely over this area, focusing principally on various sections of the mine perimeter. Table I summarizes the gas concentration results from area W2. A 50 meter transect running north from monument UL62 and crossing over the mine boundary near the sinkhole showed the highest hydrogen concentrations in the area as the transect crossed the mine perimeter (sample M62N20). Elevated hydrogen was also found, to a lesser extent, 30 meters further north (M62N50). Elevated hydrogen was found in soil gas samples above the mine perimeter at 2 other points in the area. Only one of eight samples taken inboard of the mine perimeter showed elevated hydrogen concentrations, whereas 4 of 5 samples taken above the perimeter showed elevated hydrogen. The only substantially elevated methane concentration was in the soil gas sample taken near monument UL60. Samples taken 15-20 meters north of UL60, and also a sample from 50 meters north of UL62 showed very slightly elevated methane concentrations. Only two samples contained detectable higher hydrocarbons at low ppb levels and they both contained ethane and ethylene at equal concentrations. Samples taken at the edge of the sinkhole contained low concentrations of both hydrogen and methane.

DISCUSSION

The present results from the soil gas survey at Weeks Island can be divided into two main findings: first, there appears to be a correlation of soil gas anomalies with anomalous salt zones and associated subsurface features and, second, there is an apparent correlation of soil gas anomalies with possible increased dilatancy related to mine structures.

The most dramatic result from this gas survey was the occurrence of methane and hydrogen concentration spikes at the 250 meter point of transect WK. The soil gas at that point also included significant amounts of saturated hydrocarbons, namely ethane propane. An area along transect WL, located near a drainage ditch, had similarly high concentrations of methane that is likely to be of near surface biogenic origin. Chromatographic analysis of the soil gas from the two locations showed that while the suspected biogenic methane was the only hydrocarbon in the sample, the soil gas from transect WK also contained ppm levels of ethane and propane. This clearly distinguishes the two locations and strongly suggests that the methane at WK250 is not of near-surface biogenic origin.

Further, the absence of unsaturated hydrocarbons (e.g., ethylene) also suggests that the source is not biogenic. In fact, the composition is more suggestive of a direct headspace sample of unweathered oil or wet gas.

The absence of alkenes in the soil gas also differentiates the soil gas at WK250 from all other samples taken at Weeks Island. Firm conclusions would require further investigation, but current results suggest several possibilities. It seems highly likely that the soil gas at WK250 is related to a high permeability pathway from a subsurface source. The pathway may be associated with Shear Zone D though this is slightly more speculative with only a single transect across the area. Coincidence with a topographic break thought to be related to Shear Zone D, however, introduces the possibility that the gas anomaly could have a source in the anomalous salt of Shear Zone D. Alternatively, the source could also be an oil or gas pocket in the salt not associated with Shear Zone D, or from the SPR repository oil . An important possibility regarding gas sources is that the gasses may emanate from multiple sources, but are then conducted through a common fracture pattern in their upward migration. For example, the methane and hydrocarbons could emanate from gas pockets in the salt while the hydrogen permeates through the salt barrier from the SPR repository oil or is generated by the mixing of meteoric water into deep zones with ferrous mineral constituents (FeO). It should be noted that at this point, source attributions are only hypotheses and the survey data to date cannot distinguish their relative likelihood.

Evidence for the effect of the mine structure on soil gas concentrations can be found at three separate locations around the island. First is the area encompassed by the northern section of transects WK and WL which lie in similar orientation to the perimeter of the lower mine level. The second location, area W2, is adjacent to the sinkhole on the northwestern perimeter of the upper mine where 20 samples were obtained at various locations near the mine perimeter. Finally, data from transect WM, along the eastern perimeter of the upper mine, allowed comparison of sample locations with similar landscape positions but different positions with respect to the mine perimeter.

The hydrogen profile across the 400 meter position of transect WK showed a significant break, with hydrogen concentrations at the northern extreme (>550m) of the transect being approximately an order of magnitude less than concentrations at positions just south of the 400 meter position (Figure 4a). WK400 was near the point that the transect crosses over the lower mine boundary, but also near the mapped location of an intersection of Shear Zones A and D. The differences between points north and south of WK400 may reflect a weak effect of the mine dilatancy, an anomaly related to the intersection of the shear zone, or simply an echo of the stronger anomaly at WK250 caused by subsidiary microfracturing. Hydrogen concentrations from transect WL, which lies in similar relationship to the mine boundary, compare similarly with the northern extreme of transect WK although the difference was not as large. Fewer methane results were available, but the comparison seems to hold for methane as well. Comparisons between the northern extreme of transect WK and transect WL should be taken cautiously, however, as the concentrations are low, the number of data points is small and, most importantly, they are situated near a boundary between differing soil types. The effect of soil type on gas concentrations can not be ruled out in accounting for the higher concentrations at WL compared with the northern extreme of transect WK.

Soil type difference was not a factor in the results from area W2. All samples from area W2 were from brown silty loess soils on landscape ridges adjacent to a ravine. The soil gas concentrations of hydrogen, especially, and methane showed strong evidence of higher concentrations in samples associated with the mine edge, and particularly with the edge near the sinkhole. Few of the samples were clearly outboard of the mine perimeter at this location so the composition of the soil gas further beyond the perimeter remains unknown. Further, there is no reason to expect that the surface soil gas expression of a dilatency effect would show up as a spike directly above the subsurface feature itself. That the presentation of these data may make that implication may be simply a coincidence or the result of a relatively small data set. Additional transects from inboard to outboard of the mine perimeter boundary could show a pattern that correlates to dilatancy structures formed along the mine perimeter.

Aspects of the survey along transect WM were designed to further investigate the effect of mine boundaries on soil gas concentrations. The effect of landscape position is clearly visible in the hydrogen profile of this transect (Figure 6), which was cut by several ravines; highs in the profile generally relate to higher landscape positions. The locations along the transect where additional inboard and/or outboard samples were taken were locations where the inboard, outboard, and edge samples could be taken from the same landscape position. On examining the results presented in Figures 6a and 6b two relationships become evident. First, landscape position and position with respect to the mine boundary affects the concentration of both hydrogen and, seemingly, methane. When similar landscape positions are compared– such as at 45 meters, 120 meters, 180 meters, and 210 meters on the transect– the samples outside the mine perimeter have higher concentrations than those above the mine edge and above the mine proper. Here again is preliminary evidence that the presence of the mine boundary affects the soil gas results. This could be the same effect as seen in the 0-100 meter section of transect WK; although that data is confounded by the presence of a gravel and dirt road near the transect. Also, the samples from the first 100m of transect WK are somewhat further outboard of the mine perimeter than are the samples from transect WM. The evidence would be more convincing with supporting results from longer transects, analogous to transect WK, running from slightly inboard of the mine boundary to a point beyond the lower mine boundary. This would presumably include a surface expression of Shear Zone D similar to WK250. The second relationship, again accounting for landscape differences, is the general decrease in concentrations with position along the transect. If dilatancy is a contributor to increased soil gas concentrations of the target analytes, then one may ask if the higher concentrations in this area represent significantly increased risk of subsidence. The results from area W2, scant though they are, suggest that the soil gas anomalies may be of greater magnitude on the mine boundary near the sinkhole. Thus the portion of transect WM with the most elevated readings warrants additional investigation.

CONCLUSIONS

The results of the current near-surface soil gas survey of Weeks Island suggest a significant relationship between anomalies in surface soil gas concentrations and subsurface features such as anomalous zones in the salt and dilatant zones associated with the mine structures at Weeks Island. The surface expression of an anomalous salt zone, Shear Zone D, has been tentatively identified on the basis of soil gas profiles. The results also have repeatedly suggested that dilatancy associated with the mines leads to anomalously high concentrations of hydrogen and possibly methane as well. The limited size and scope of the sampling design has left unanswered important questions about the source and transport of the anomalous gas, especially with respect to the effect of the mine structure. The extended hydrocarbon analysis of the C2+ hydrocarbons has been useful for distinguishing different types of soil gas anomalies, specifically for distinguishing near surface biogenic anomalies from more important subsurface related anomalies.

In conjunction with other geological interpretations this near-surface gas mapping technique can be very useful in elucidating subsurface structure and for site characterizations. While the data from this small survey are certainly not comprehensive or fully conclusive on their own, they demonstrate that a soil gas survey can provide complementary information that is both valuable and easily obtainable to investigations of salt dome structures. This technique is appreciably less expensive, quicker, and simpler than traditional geophysical diagnostic techniques, potentially yielding a distinct cost-benefit advantage in appropriate situations.

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TABLE I. **Area W2 results summary.**

Position	IN/OUT	hydrogen*	methane*	comment
from Sinkhole				
3 m N		nd	—	
7 m N		nd	1.8	
3 m S		nd	1.3	
7 m S		nd	1.7	
from UL62				
3 m N	IN	1	—	
10. m N	IN	39	—	
20 m N	EDGE	434	—	highest reading in area
20 m N	EDGE	285	—	
30 m N	OUT	5	—	
40 m N	OUT	32	—	
50 m N	OUT	162	3.2	near a corner
from UL61				
1 m N	IN	2	2.3	
15 m N	IN	5	1.2	
from UL60				
1 m N	IN	6	6.5	near a corner
15 m N	EDGE	100	3.2	near a corner
25 m NW	OUT	nd	2.6	near a corner
from UL 57				
1 m N	IN	150	—	
15 m N	IN	6	1.5	
25 m NW	EDGE	245	—	
from UL 56				
1 m SE	IN	11		near a corner

* Values are chromatographic peak areas. To convert to ppmv, multiply by 0.7 for hydrogen and by 1 for methane.

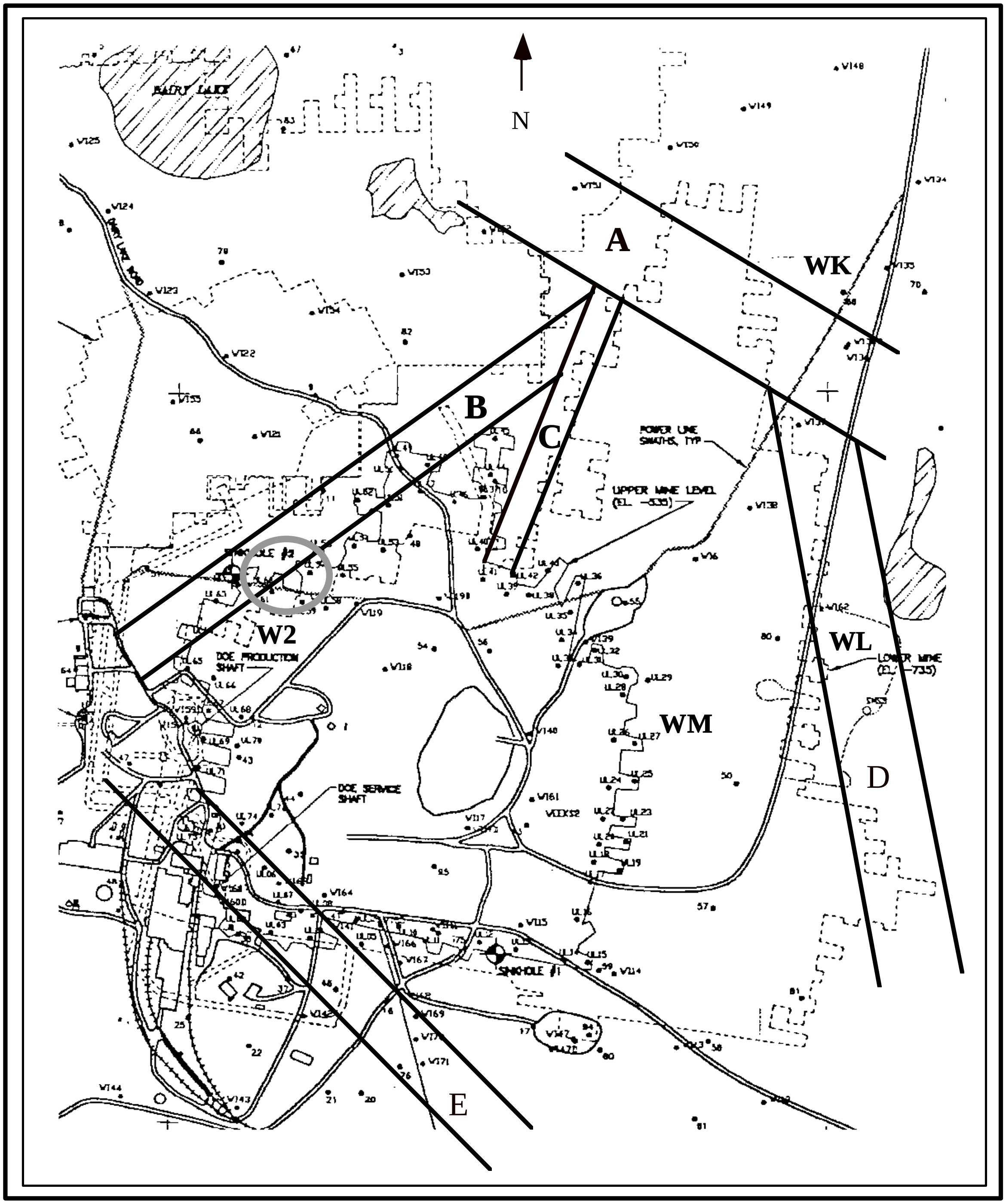


Figure 1. Map of Weeks Island showing mapped shear zones and sampling transects (after ref. 5).

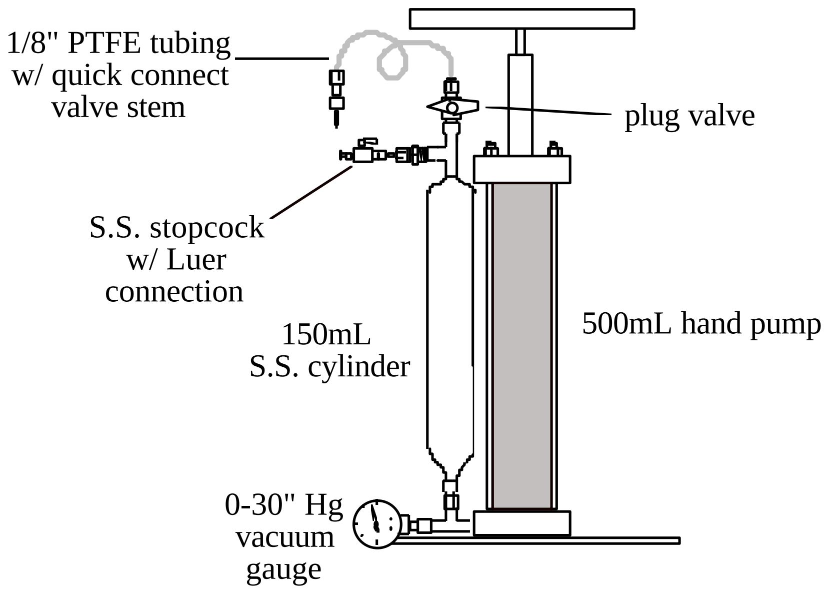

1/8" PTFE tubing
w/ quick connect
valve stem
plug valve
S.S. stopcock
w/ Luer
connection
150mL
S.S. cylinder
500mL hand pump
0-30" Hg
vacuum
gauge

Figure 2. Diagram of portable soil gas sampler.

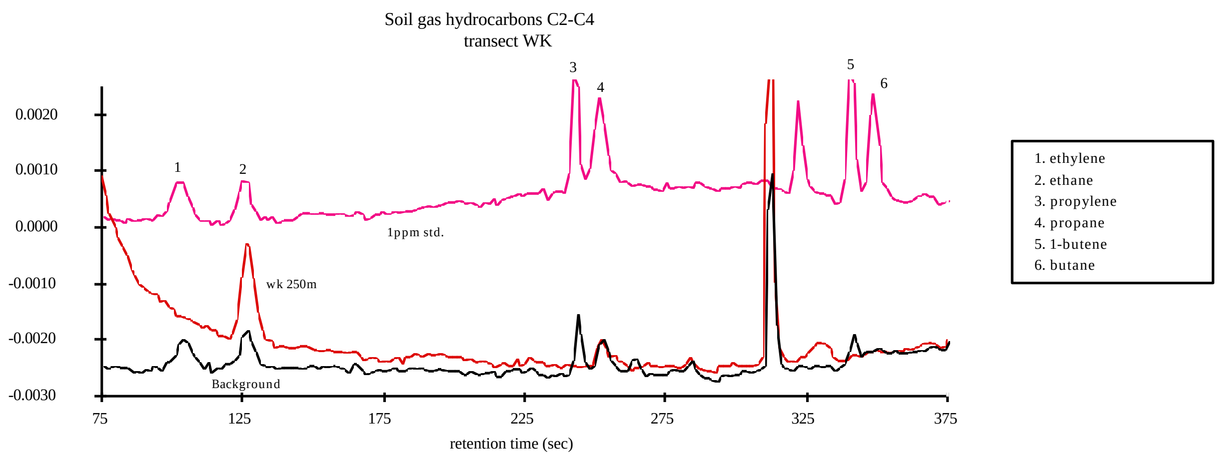
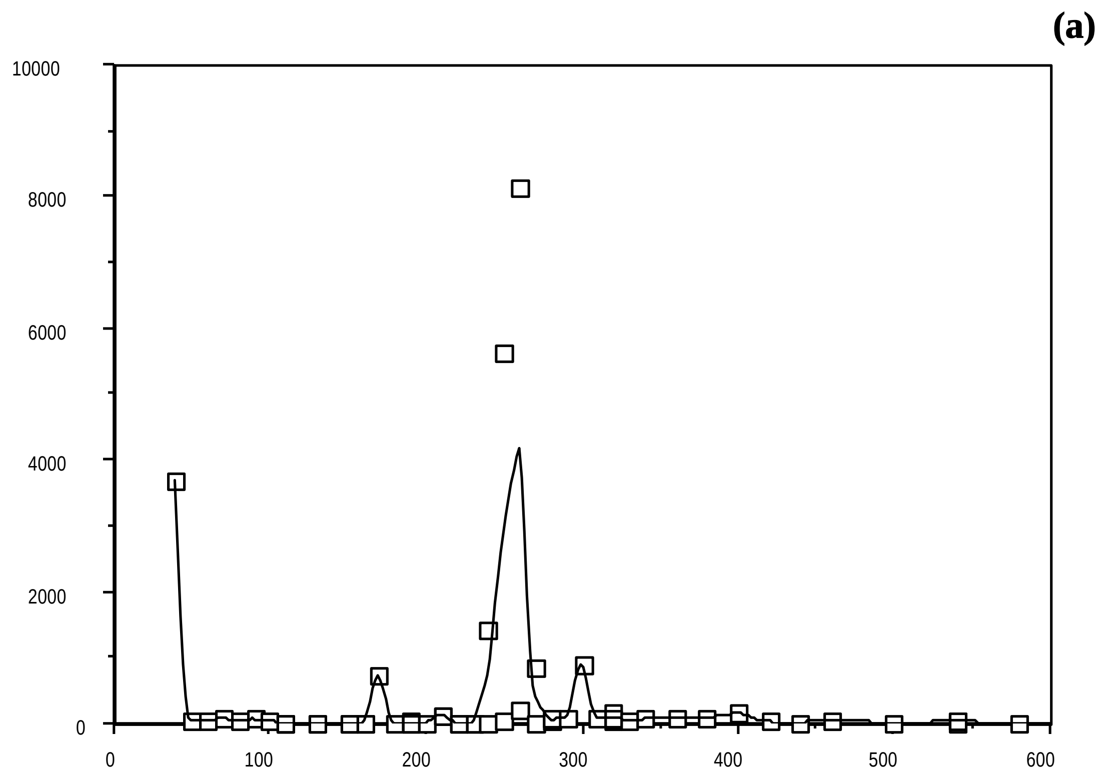


Figure 3. Chromatographic traces showing hydrocarbon profile for two different locations at Weeks Island



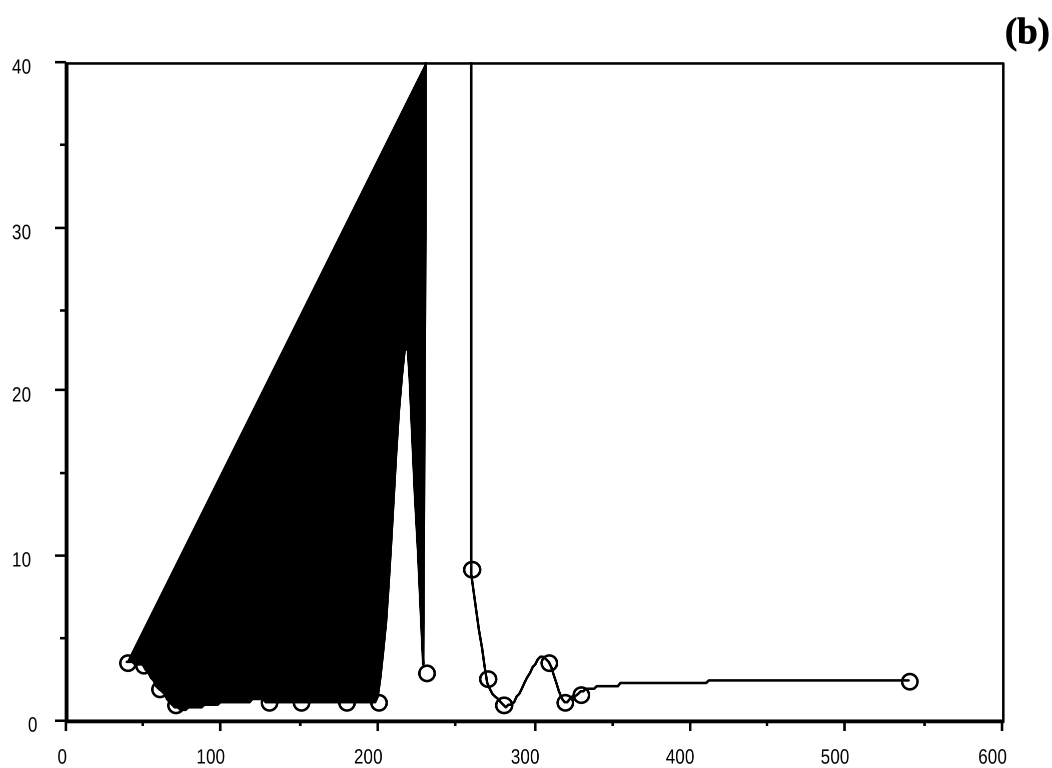


Figure 4. Profile of hydrogen (a) and methane (b) concentrations across transect WK.

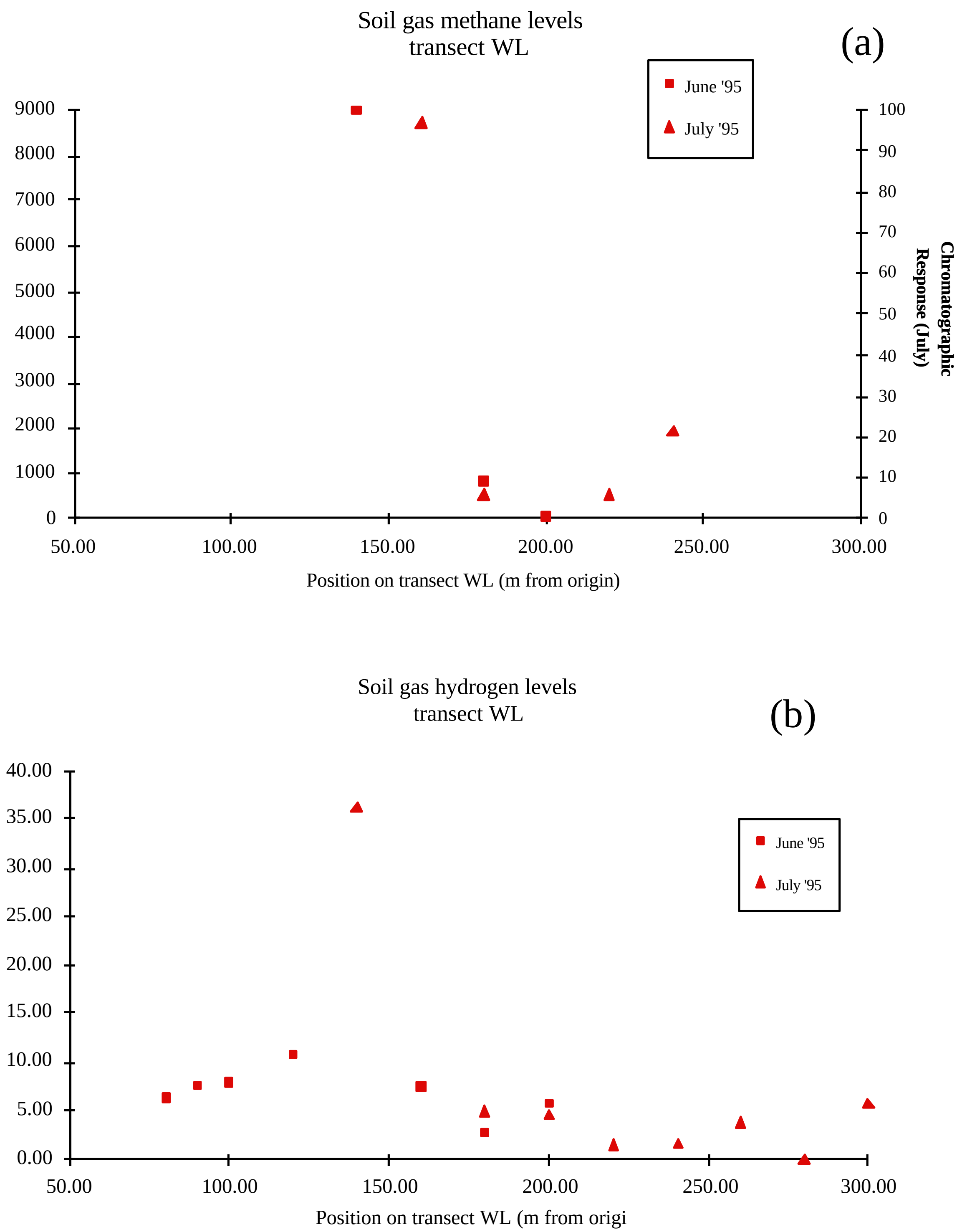
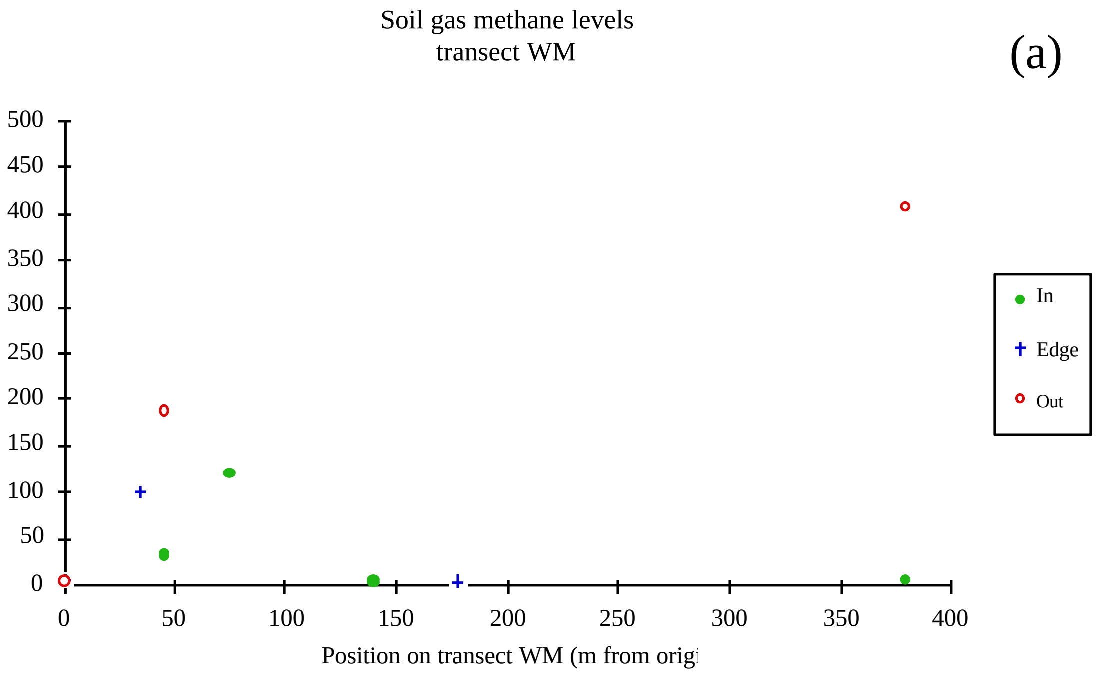


Figure 5. Profile of methane (a) and hydrogen (b) across transect WL.



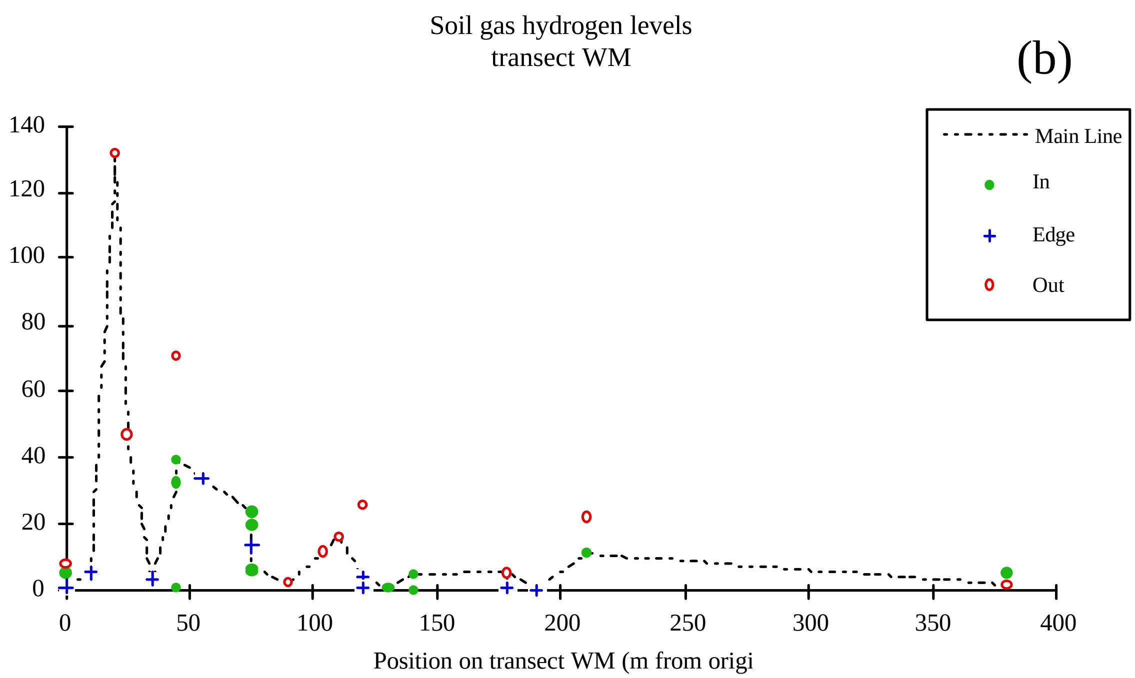


Figure 6. Profile of methane (a) and hydrogen (b) across transect WM.

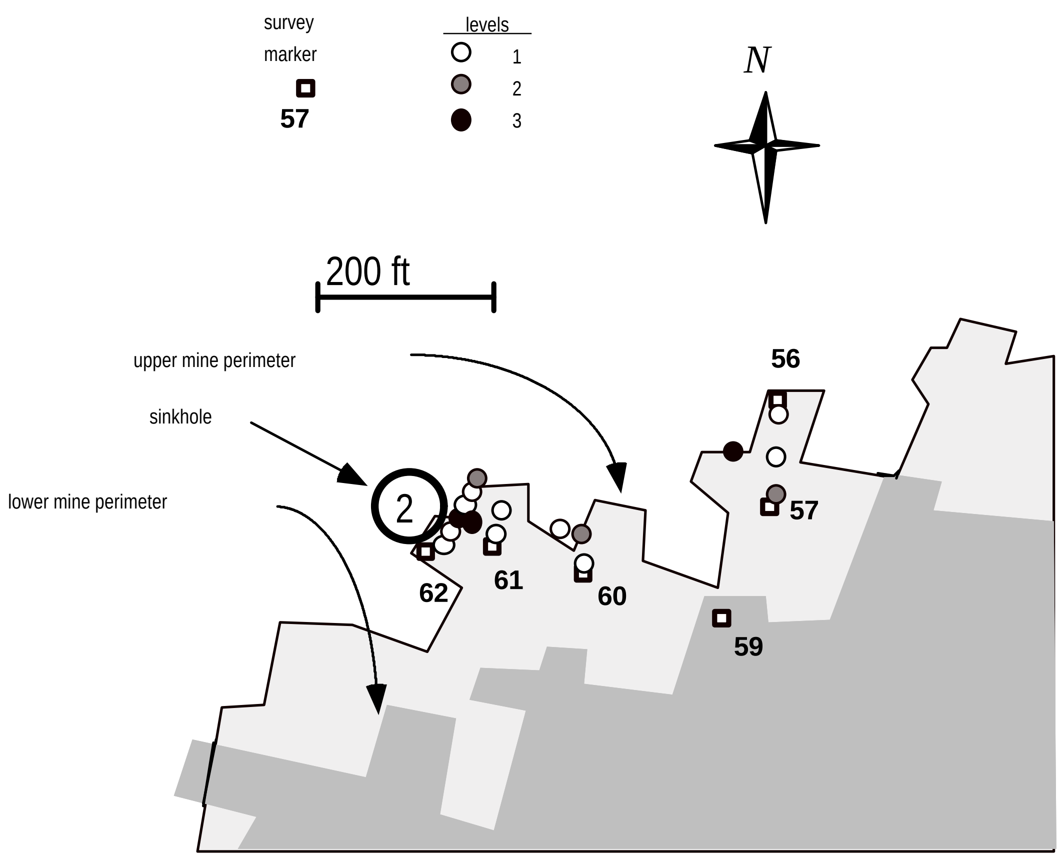


Figure 7. Distribution of hydrogen anomalies across area W2 near a recent sinkhole.